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HEAO BLOCK II STUDY EXECUTIVE SUMMARY

By Program Development

March 1976

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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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16. ABSTRACT

This document is an executive summary of a preliminary study done on several potential High Energy Astronomy Observatory (HEAO) missions which are follow-on missions to the currently defined HEAO program. This study was conducted during the period October through December 1975. The purpose was to examine several typical missions and determine the relative complexities associated with them.

The four payloads investigated were (1) a 1.2 m Diameter X-ray Telescope observatory, (2) a Large Area Moderate Angular Resolution (LAMAR) observatory, (3) a cosmic ray observatory, and (4) a gamma ray observatory. Each of the four observatories was considered a national facility.

Low cost approaches were stressed throughout the study, with considerable use of HEAO Block I experience and designs effected to provide a high degree of confidence that such approaches were achievable. The use of the Multi-Mission Spacecraft (MMS) and the HEAO Block I spacecraft was considered in the study as a result of this low cost emphasis. Also, NASA standard components were considered where applicable.

The study was limited to a technical activity; no programmatic analyses were performed.

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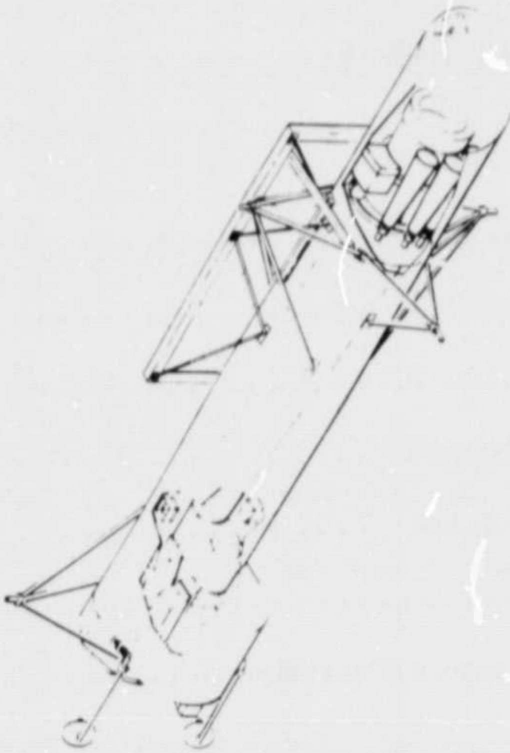

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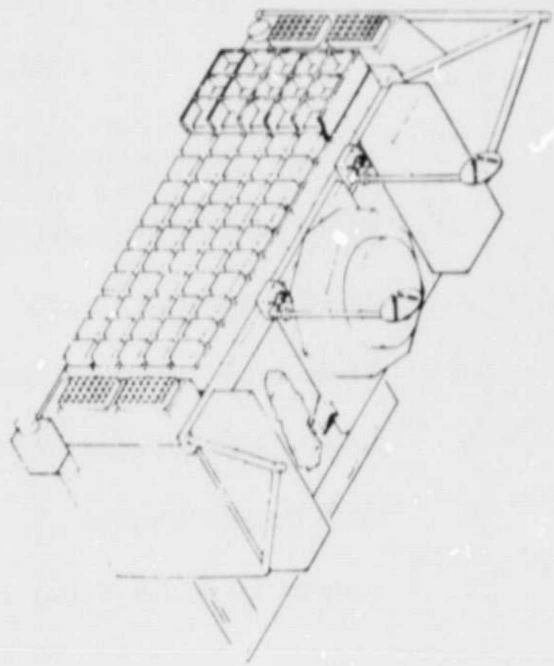

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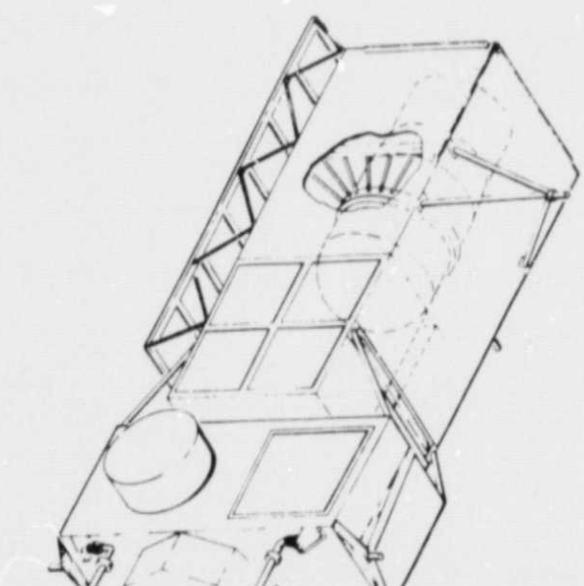

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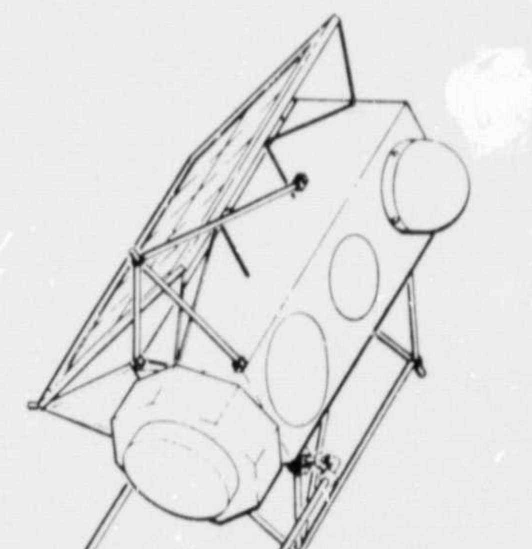

GAMMA RAY OBSERVATORY

TECHNICAL MEMORANDUM X-73318

HEAO BLOCK II STUDY EXECUTIVE SUMMARY

I. INTRODUCTION

A. Background and Study Approach

The Marshall Space Flight Center (MSFC) was asked to define feasible missions as a continuance of the High Energy Astronomy Observatory (HEAO) program currently being implemented. The follow-on effort, or Block II, is visualized as a series of missions that take advantage of the capabilities of the Space Shuttle in such areas as heavy payload capability, retrieval of payloads, and frequent flight opportunities. Hence, the Block II experiments are expected to have greater dimensions and mass to afford larger collecting areas, improved sensitivities, and better spectral and angular resolution. The observatory candidates defined herein are envisioned as national facilities, and their retrieval and reuse will allow a maximum number of scientific investigators to conduct studies, thus permitting greater scientific continuity and maximum scientific return per dollar invested.

Although an initial funding request for two missions is anticipated, the feasibility of four different mission options was studied. In accordance with Space Science Board (SSB) recommendations, "typical" mission options were developed for a 1.2 m X-Ray Telescope, a cosmic ray mission, a medium energy gamma ray mission, and a Large Area Moderate Angular Resolution (LAMAR) X-ray mission. The scientific community has expressed an interest in the objectives of the Block II missions and has developed technologies and ideas suitable for Shuttle-launched, free-flyer, observatory-type facilities. The actual flight instrumentation will be selected following an Announcement of Opportunity.

The use of standard hardware was emphasized throughout the study. By using an existing spacecraft, development costs for a new spacecraft are avoided, and experiment design and integration are simplified by working with a well-defined systems interface. The spacecraft portion of this study concentrated on the HEAO spacecraft and the Multi-Mission Spacecraft (MMS) because these promised adequate capability. Because the HEAO spacecraft is well into the hardware phase, much greater depth of design information exists on this system. The MMS was studied to the extent that available documentation allowed.

The study results were documented in an informal MSFC report "High Energy Astronomy Observatory (HEAO) Block II Study," dated December 1975, by Program Development, MSFC, for which this report is an executive summary.

B. Science Background

1. 1.2 m X-RAY TELESCOPE MISSION

In the coming decade, X-ray observations will likely be extended to the coronas of main-sequence and giant late-type stars, as well as to peculiar stars such as flare stars. It will also be possible to detect and resolve clusters of galaxies at extreme distances ($Z = 3$) and to study their evolution over times comparable with the age of the universe. X-ray emission from clusters of galaxies is likely to originate in the heretofore unobserved intergalactic medium, which may contain a large fraction of the total observable mass of the universe. These studies will profoundly influence our understanding of the dynamics and evolution of the cosmos. The scientific questions of X-ray astronomy translate into long range, observational objectives such as high sensitivity surveys, high resolution spectroscopy of selected sources, polarimetry of selected sources, and study of time structure.

The 1.2 m X-Ray Telescope considered in this study, when compared with the Block I telescope, has approximately 4 times the resolution, 4.5 times the collecting area at long wavelengths, and approximately an order of magnitude more collecting area at short wavelengths. This allows for shorter observation time and investigations of fainter and finer structured sources.

2. LAMAR MISSION

High sensitivity surveys for very faint sources cannot be efficiently conducted with large-area proportional counters using conventional mechanical collimators because of source confusion. To search for even fainter sources, it is necessary to combine large area with moderate angular resolution. While focusing X-ray telescopes have extremely fine angular resolution (better than 1 s of arc), they cannot easily achieve large areas. Thus, the measurement of the spectrum of the faintest sources and the measurement of time variations of 10^{36} erg/s sources in external galaxies can most conveniently be accommodated by a mission such as the LAMAR.

3. COSMIC RAY MISSION

Galactic cosmic rays include all nuclei in the periodic table of elements, as well as electrons and positrons. Their energies span the range at least from

10^6 eV to 10^{20} eV. The cosmic ray flux appears to be isotropic, reaching the Earth with the same intensity in all directions. Cosmic ray research can lead to an understanding of the evolution of matter in the universe through a knowledge of the cosmic ray composition. Cosmic ray research is also closely related to other areas of research in astrophysics such as radio astronomy, X-ray and gamma ray astronomy, and stellar evolution.

The instrumentation visualized for use on the cosmic ray mission should accomplish four major objectives: High energy spectra, charge composition and arrival direction; high-Z elemental abundances; isotopic abundances; and electron and positron energy spectra.

4. GAMMA RAY MISSION

Gamma ray astronomy provides an excellent, and in some respects a unique, way of obtaining information on high energy particles and processes in the universe, currently and in the remote past. Of all parts of the electromagnetic spectrum, only this one measures the presence and effects of energetic nuclei and antiparticles directly, while also preserving the directional and time features of the sources. Gamma rays result from quite different mechanisms than those that produce most of the cosmic X-rays; hence, they convey different types of information. They retain the detailed imprint of spectral, directional, and temporal features imposed at their birth, even if they were born deep in regions opaque to visible light and X-rays or at times far back in the evolutionary history of the universe.

An intensive effort to determine the nature and detailed features of the discrete sources and the gamma ray continuum, to measure the spectral structure and understand the origin of the diffuse background, and to detect nuclear line radiation from galactic and extragalactic sources will not only solve or sharply delineate many astrophysical questions, but will set the stage for exciting new discoveries. The HEAO Block II gamma ray astronomy mission will be able to carry large gamma ray instruments directed toward meeting these objectives.

II. MISSION DEFINITION

A. Mission Requirements and Descriptions

All of the HEAO Block II missions are intended to be observatory-type missions with long life, multiastronomer use, and capability for exchange of

instruments. The observatories were specified to be launched and retrieved by the Shuttle. The nominal time between servicing of the observatories was selected as 2 years for the purposes of this study, but this could in fact vary as the requirements of a given payload demanded. The launch dates chosen for study were mid-1982 for the 1.2 m X-Ray Telescope, mid-1984 for the LAMAR and cosmic ray payloads, and mid-1986 for the gamma ray payload. The orbit parameters were selected to minimize exposure to radiation belts and to provide adequate orbital lifetime. All payloads except the cosmic ray payload preferred a low orbit inclination (near zero) to minimize radiation belt exposure, and the cosmic ray payload preferred a higher inclination (28.5 to 55°) to minimize the Earth's magnetic field interactions with particles. These orbit preferences were traded with the Shuttle performance capability, and orbits were selected for each mission as discussed in Section III.

The X-ray telescope and LAMAR missions are pointing missions, and the gamma ray mission is primarily a pointing mission but some scanning will probably be desired. The cosmic ray mission has no specific orientation requirement except that occultation of the fields of view should be minimized and the solar array must be pointed toward the Sun.

The X-ray telescope mission was examined in more detail than the others because it is a good representative mission and more data were readily available for it. The alignment tolerances for the telescope are ±0.7 mils lateral displacement, ±4 mils axial displacement, and ±10 arc s mirror tilt. The most stringent of these requirements to meet is the lateral displacement tolerance, and during this study, a telescope concept was defined that can meet these tolerances.

B. Mission Equipment Description

1. 1.2 m X-RAY TELESCOPE

The 1.2 m X-Ray Telescope contains a focusing, grazing-incidence, Wolter Type I mirror at the front end and a number of associated detectors near the aft end. It has a field of view of 0.5 to 1°, a focal length of 28 ft, and a resolution of approximately 1 arc s over the energy range from 0.1 to 5 keV. The focal plane detectors are mounted on a carrousel, with only one operating at a time. The focal plane instruments include two imaging proportional counters, three high resolution imagers, a crystal spectrometer, a solid state spectrometer, and a polarimeter. Nonfocal plane equipment includes an objective grating, a monitor proportional counter, four X-ray monitor detectors, and an aspect system.

The total weight of the mission equipment is 10 767 lb, of which 8738 lb is due to the mirror assembly. The power requirement of 272 W is the maximum power expected for the instruments on this payload. The requirement will be lower for some combinations of operating instruments and those on standby status. The 5.4 kbps data rate for the mission equipment is low, primarily because only one focal plane instrument may be operated at a time.

2. LAMAR

The LAMAR observatory mission equipment consists of an array of 65 collector assemblies and 65 detector assemblies. Four proportional counter modules are also provided. Each collector assembly has an area of 18 by 18 $in.^2$ and each consists of two Baez reflectors. The detector assemblies are imaging proportional counters. The LAMAR array can observe X-ray sources within the energy range of 0.1 to 4 keV, has a field of view of 1 by 1°, and has an angular resolution of 1 arc min. The four proportional counter modules allow observation of sources within the energy range from 0.1 to 100 keV, although resolution and sensitivity are less than that of the array. The total weight of the mission equipment is 11 809 lb. The power requirement is 335 W and the data rate is 32 kbps.

3. COSMIC RAY

The cosmic ray observatory mission equipment consists of a magnetic spectrometer, high-Z elemental abundance instruments, isotopic abundance instruments, and a transition radiation detector. All instruments view at least in two, and some in three, directions and all have large composite fields of view, on the order of ±65 to ±120°. The total weight of the mission equipment is 14 300 lb. The power requirement is 269 W and the data rate is 15.3 kbps. The lifetime of the magnetic spectrometer is expected to be only 1 year; hence, the power and data requirements will decrease to 185 W and 8.4 kbps, respectively, in the second year.

4. GAMMA RAY

The gamma ray observatory mission equipment consists of a high resolution cryogenically cooled Ge (Li) gamma ray spectrometer, a low and medium energy actively shielded instrument, and a medium energy gamma ray monitor. The fields of view are large, ranging from ±30 to ±90°, and the composite energy range is from 0.06 to 20 MeV. The total weight of the mission equipment is 13 499 lb, of which 11 000 lb are due to the low and medium energy instrument. The total power and data rate requirements are 225 W and 25.4 kbps, respectively.

III. MISSION ANALYSIS AND OPERATIONS

A. Orbit Selection

The dominant orbital selection factors were the 2-year operational lifetime requirement and the Shuttle launch and retrieval compatibility requirement. Other considerations that influence orbit selection for scientific payloads are (1) South Atlantic Anomaly (SAA) contact and subsequent trapped, charged particle impingement, and (2) location and availability of viewing sources. These considerations were addressed in considerable detail during the course of this study but are only summarized in this section.

Figure 1 shows an altitude decay history for each Block II payload beginning at an initial placement altitude range of 207 to 235 n. mi. The 2σ (worst case) atmospheric density variation (1970 Jachia) model, along with a maximum drag orientation for each HEAO Block II payload, was assumed for this analysis. Launch dates were as shown on Figure 1.

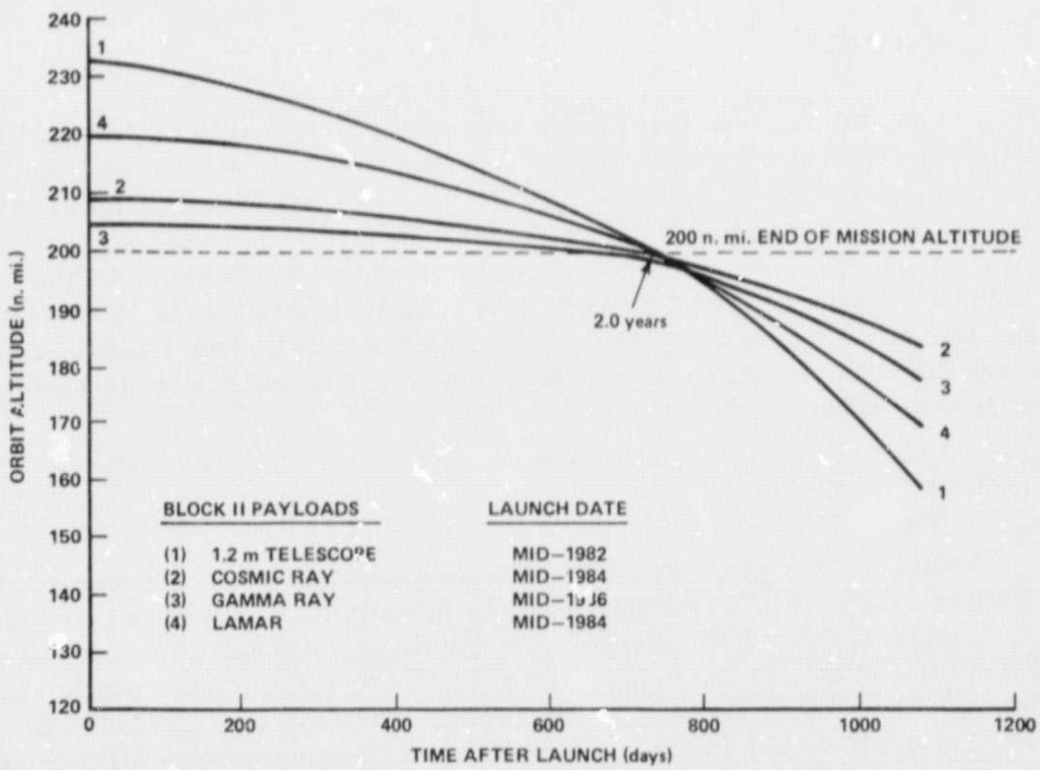

Figure 1. HEAO Block II altitude decay histories.

The Shuttle launch and retrieval guideline for this study had no impact on the desired altitude for the Block II payloads; however, there are Shuttle performance penalties when inclinations lower than 28.5° are desired. On-orbit ΔV requirements are approximately equivalent to one Orbiter Maneuvering System (OMS) kit per degree of desired plane change. Trying to achieve an inclination lower than 28.5° from the Kennedy Space Center (KSC) Eastern Test Range (ETR) launch site by flying a southerly azimuth and using yaw steering or "doglegging" orbit injection methods places an even greater fuel consumption problem (payload penalty) on the Shuttle than requirements cited for on-orbit plane changes. There are no significant Shuttle launch performance impacts for the range of orbital inclinations from 28.5 to 55.0°.

Preliminary Shuttle performance analysis at MSFC has shown that the 65 000 lb payload capability for due east launches (28.5°, ETR) was reduced to a 20 000 lb capability in achieving 25.4° inclined orbit. This means that the Shuttle payload-to-orbit capability would go to zero before an analogous HEAO-B inclination (22.75°) was achieved. A 28.5° minimum inclination for the Block II payloads was selected, which gives considerable Shuttle flight-sharing capability with other payloads.

B. Viewing Analysis

A list of nine typical targets was chosen from the Uhuru catalog for use in a simulated observing analysis for the HEAO-B (Block I) focal plane instruments over a 1 week period. The Block II simulated observation analysis utilized this set of target selections with some modifications of the viewing time allotted per focal plane instrument. Figure 2 shows the relative HEAO-B/Block II telescope orbital parameters, source target locations, and viewing constraints. The relative motion of the HEAO-B and Block II orbit planes, i.e., 22.75° inclination versus 28.5° inclination, on the inertial celestial sphere shows that the 28.5° inclination has no adverse effect on viewing opportunities for this set of representative targets.

An additional viewing constraint in a typical observing timeline occurs when certain portions of the SAA are encountered. Specific orbital contact with this anomaly region will have a varying impact on communications and data gathering functions of the HEAO Block II payloads, depending on the relative sensitivity of the instruments. Detailed information concerning the relative sensitivity of each Block II instrument was not available for these "strawman" payloads. However, for the detailed observation timeline performed for the 1.2 m X-Ray Telescope, an electron energy range of $E > 0.0$ MeV and an

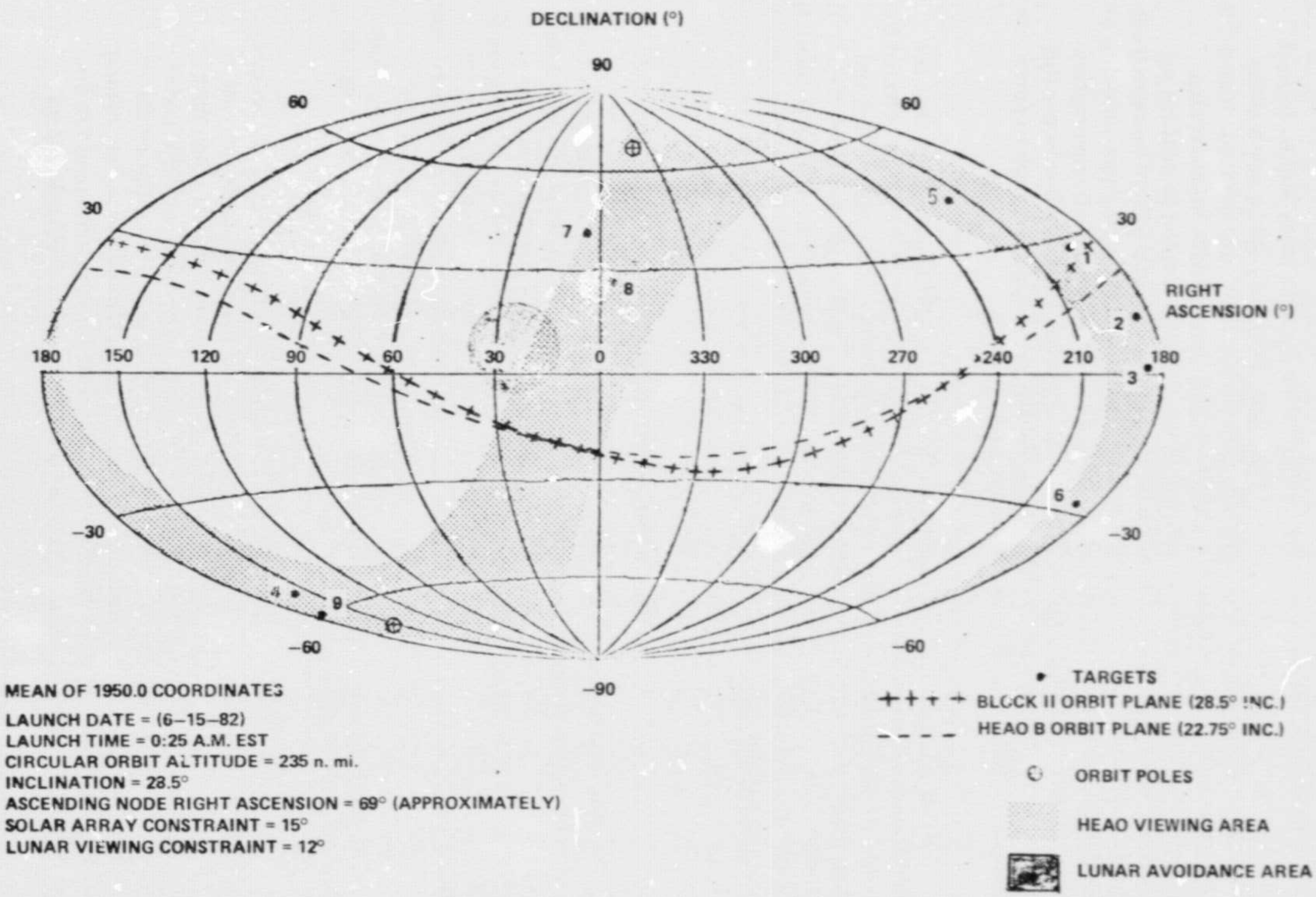

Figure 2. Celestial sphere viewing geometry at first nodal passage on June 29, 1982.

intensity count rate of 10^4 particles/s were assumed, which resulted in an average experiment "deadtime" of approximately 7.0 percent. A summary of the results of the observation simulation for the 1.2 m X-Ray Telescope is shown in Table 1.

TABLE 1. 1.2 m X-RAY TELESCOPE OBSERVING TIMELINE SUMMARY

Total Actual Observing Duration = 8370 min (5.81 days)
Total Observation Time (all instruments) = 5909 min (70.59%)
Total SAA Encounter Time = 611 min (7.3%)
Total Viewing Time Affected by SAA Contact = 428 min (5.1%)
Total Slew + Reconfiguration Time = 1510 min (18.04%)
Total Idle Time = 951 min (11.36%)

IV. OBSERVATORY CONFIGURATIONS AND ANALYSES

A. Configurations and Analyses

The HEAO spacecraft is utilized with each of the configurations shown in this section of the report. The modifications required to the HEAO spacecraft are identified in Section V. The MMS configurations and MMS modifications are provided in Section VI.

1. 1.2 m X-RAY TELESCOPE OBSERVATORY

The observatory configuration has a 28 ft focal length telescope as shown in Figure 3. The total length of the observatory is approximately 44 ft. The insulated aluminum outer shell provides attachment for the solar array, Tracking and Data Relay Satellite System (TDRSS) antennas, magnetic control system, spacecraft, and all-sky monitor instruments. It also supports the internal optical bench and instrument assembly and provides structural attachment to the orbiter through fixed strut members. Internally, provisions are made for support of nonfocal plane electronics, etc.

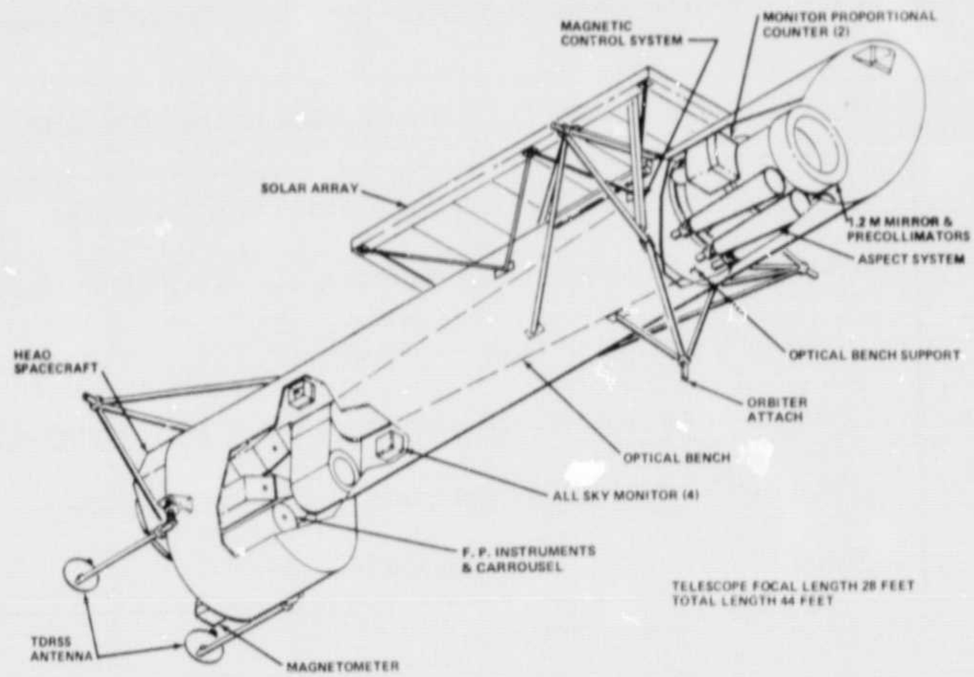

Figure 3. 1.2 m telescope.

The telescope assembly consisting of the mirror, collimators, objective grating, monitor proportional counters, aspect system, focal plane instruments and carrousel, optical bench, and carrousel support structure is attached near the composite center of gravity (c.g.) to the external shell by a graphite/epoxy cone. The optical bench is graphite/epoxy. An offset cylindrical extension at the detector end of the bench provides cantilevered support for the rotating carrousel which positions instruments at the focal point. The carrousel and support structure is assumed to be a combination of graphite/epoxy and Invar materials. The single cone connection of the assembly to the outer shell was chosen to avoid outer shell thermal distortion coupling with the optical bench. Preliminary analysis indicates feasibility of the approach.

The solar array consists of a fixed array of 14 HEAO modules (approximately 29 by 54 in. each) that are interconnected and supported around the periphery. A separator panel between the two seven-panel arrays is provided to improve the view factor on the back side of the array for heat rejection. Two TDRSS antennas are provided with a two-axis drive capability for pointing. The spacecraft is attached at the HEAO Block I experiment interface points.

A preliminary structural analysis was made on the 1.2 m X-Ray Telescope optical bench and its supporting structure.

By supporting the optical bench from the outer shell structure at a single point, the optical bench is isolated from loads originating at the orbiter/payload support points, the solar array, and the spacecraft and from thermal distortion of the outer shell. This structural arrangement does, however, produce a system of limited stiffness because of the cantilevered effect of the mirror assembly and the focal plane instruments. The optical bench is sized for minimum stress at 4 g lateral acceleration and has the following characteristics: natural frequency = 8.85 Hz, deflection = 0.5 in., and section thickness = 0.19 in. The optical bench tube itself weighs approximately 578 lb, and the support structure and carrousel bring the total to 1403 lb. It is evident from the analysis performed in the study that a reasonable optical bench structure can be configured using a single support.

The maximum allowable optical bench axial deformation of ±4 mils would permit a ±44°C axial temperature gradient. The maximum allowable optical bench decenter of ±0.7 mil would permit a ±1.02°C temperature difference between diametrically opposed surfaces of the optical bench. This resulted in the most stringent thermal control requirement. The maximum allowable tilt of 10 arc s produces an allowable ±7.9°C temperature difference diagonally across the bench from one end to the other.

A thermal analysis was performed on the observatory using a 206-node model with external α/ϵ of 0.3/0.5 and internal α/ϵ of 0.03. The outer structure was sandwiched between two aluminized Mylar insulation blankets, each of which was 1.5 in. thick.

Results of the thermal analysis indicated that the maximum orbital temperature variation for the outer shell was 0.011°C. The largest temperature difference between diametrically opposed surfaces of the outer shell was 0.443°C. Temperature gradients between diametrically opposed surfaces along the length of the optical bench reached a maximum of 0.034°C, and the maximum axial gradient was 5°C. The maximum transverse and axial gradients are well below the maximum allowable requirements of 1.02°C and 44°C, respectively. The outer shell structure with insulation on both sides almost completely attenuates the temperature variations because of vehicle orientation and orbital variations.

To counter the heat leak in the radial direction for the entire optical bench, a 2.5 W heat input is required. A total of 2 W of energy will have to be placed on the optical bench to maintain a 21°C temperature, and 18 W will be required at the mirror assembly to maintain a 21°C temperature and to prevent any large temperature gradients.

Thermal analyses were performed for the solar array of the 1.2 m telescope, and results indicated temperature extremes of approximately 32 to 85°C over an orbit. These are within the allowable range and probably can be improved with further design effort.

2. LAMAR OBSERVATORY

The configuration shown in Figure 4 resulted from the requirement to provide approximately 100 ft^2 of viewing area for the LAMAR array of collectors (mirrors). The 65 module array of 5 by 13 was selected to meet orbiter bay clearance and c.g. requirements. The side-mounted location of the spacecraft was chosen to minimize control problems associated with mass moments of inertia. The spacecraft is attached to the experiment at HEAO Block I experiment interface points.

Each of the 65 mirror assemblies has a separate detector. The mirror assemblies and detector assemblies are joined respectively into separate banks which are then held in alignment with each other at the required focal length by the peripheral structure. Four separate X-ray modules are included, as well as star trackers, TDRSS antennas (two-axis drive), and a solar array. The four-point orbiter attachment structure is an integral part of the structure. The solar array, consisting of 14 HEAO modules, is fastened to the side of the observatory during launch and pivots 180° to its normal operating position as shown in Figure 4 for operation.

3. COSMIC RAY OBSERVATORY

The cosmic ray observatory configuration is shown in Figure 5. The selected experiment arrangement resulted as a compromise between minimizing control moments of inertia and separating the superconducting magnetic spectrometer from the rest of the observatory equipment because of its high intensity magnetic field. The transition radiation detector, isotopic abundances, and high-Z elemental abundances instruments have double-ended viewing as depicted, and the spectrometer is sensitive to information from three directions. The Total Absorption Shower Counter (TASC) is Sun-oriented.

A fixed solar array of 14 HEAO panels is separated from the instrument structure with standoffs. A pair of TDRSS antennas is incorporated with a two-axis drive system for antenna pointing. The instrument support structure is aluminum and is straight-sided. The cryogenic spectrometer is suspended internally with a low conductivity support system such as fiberglas/epoxy. The structure also contains the fixed orbiter attachment members and interfaces with the spacecraft at four of the eight available interface points.

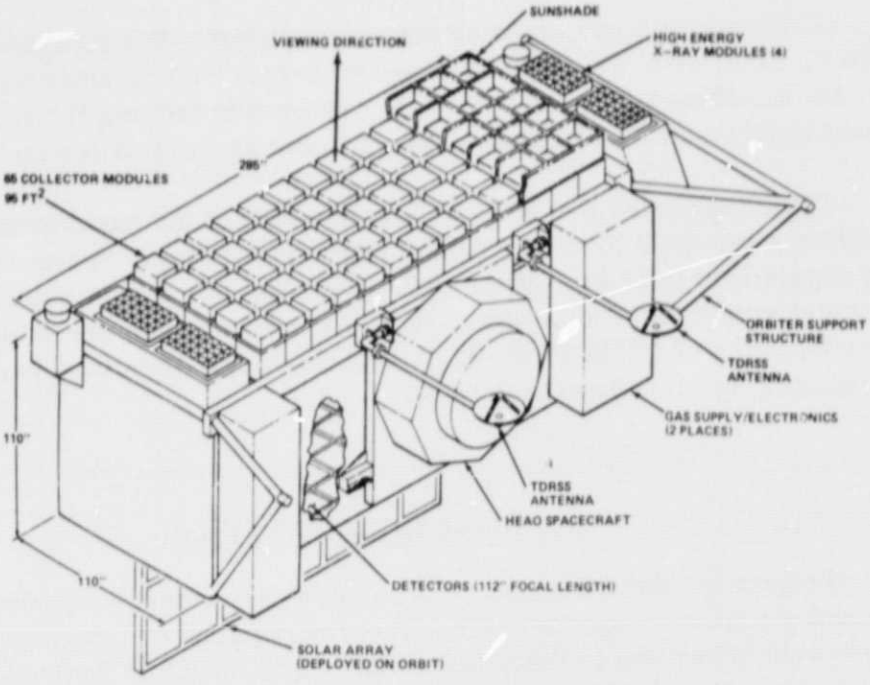

Figure 4. LAMAR observatory.

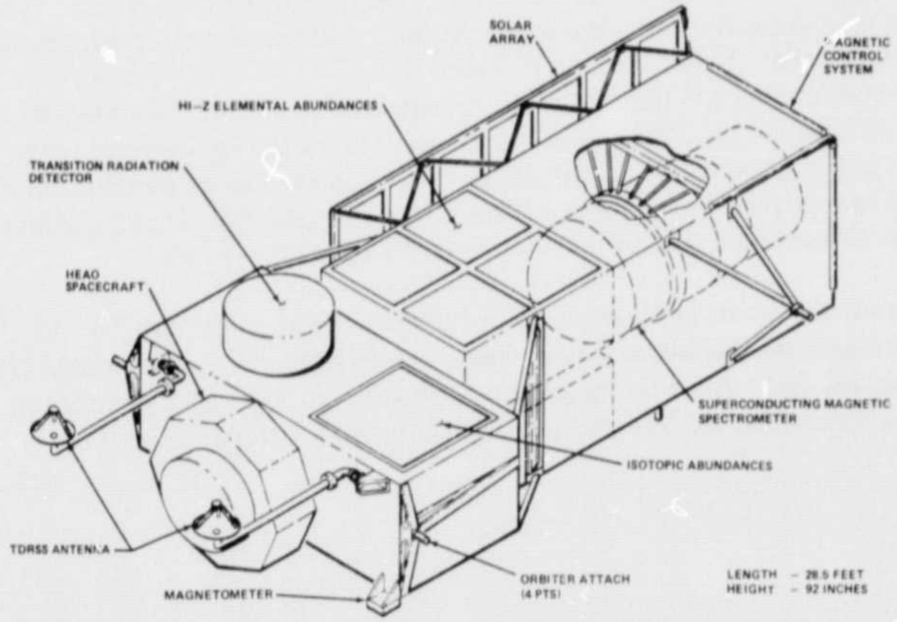

Figure 5. Cosmic ray observatory.

4. GAMMA RAY OBSERVATORY

Three gamma ray instruments are included in the configuration shown in Figure 6, along with the spacecraft, solar array, TDRSS antennas, and structure. No significant problems were encountered in this configuration. The heaviest instrument was located adjacent to the spacecraft for inertia reasons.

TDRSS antennas are stowed along the side of the experiment during launch and utilize a two-axis drive for deployment and pointing. Spacecraft attachment to the experiment is at four of the eight available attachment points. Orbiter attachment structure is an integral part of the experiment structure. The solar array consisting of 12 HEAO modules and connecting structure is positioned to avoid shading by structural members.

B. Mass Characteristics

Weights for the HEAO Block II payloads are shown in Table 2. Mission equipment structure consists of the structure required to integrate the instruments to each other and to the spacecraft. The spacecraft weights include the HEAO spacecraft with the required modifications as specified in Section V. The solar array weight includes only the solar panels; frame weight is included with the structure.

Mass characteristics for the four payloads were calculated. The maximum and minimum inertia values for the four missions are approximately 130 000/6000 slug-ft^2 for the 1.2 m telescope, 53 000/6500 slug-ft^2 for the cosmic ray, 8000/3000 slug-ft^2 for the gamma ray, and 25 000/11 500 slug-ft^2 for the LAMAR observatory. For comparison, the maximum moment of inertia of the 1.2 m X-Ray Telescope observatory is more than twice as great as that of the Space Telescope, 15 times as great as that of the Block I HEAO missions, and 400 times as great as that of a typical MMS with its payload.

Analyses were performed to determine the compatibility of the Block II observatories with the orbiter c.g. constraints in X, Y, and Z axes. The Block II payloads all fall within the c.g. envelopes for all axes as specified in Volume XIV of the Space Shuttle System Payload Accommodations document.

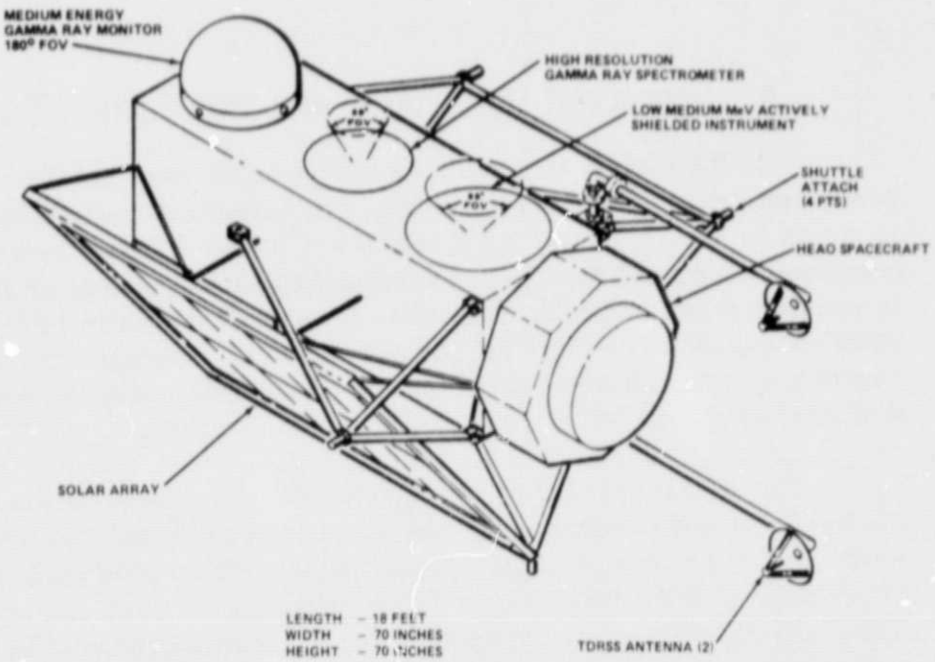

Figure 6. Gamma ray observatory.

TABLE 2. HEAO BLOCK II MISSIONS WEIGHT SUMMARY (lb)

	1.2 m X-Ray	Cosmic	Gamma	LAMAR
Instruments/Equipment	11 247	14 300	13 449	11 809
Mission Equipment Structure/Thermal Control	3 874	3 259	1 256	2 278
Spacecraft	1 556	1 587	1 434	1 403
Mission Peculiar:	874	659	463	482
Solar Array	144	144	123	144
Electrical Integration[a]	93	93	83	93
Propulsion and Pressurization	137	137	137	137
TDRSS Antennas, Booms, and Gimbals	64	64	64	64
Magnetic Torquers and Electronics	436	221	25	44
Subtotal	17 551	19 805	16 602	15 972
10 percent Contingency	1 755	1 981	1 660	1 597
Total	19 306	21 786	18 262	17 569

a. Harness, Connectors, and Experiment Accommodation Assembly

V. HEAO SPACECRAFT MODIFICATION ANALYSIS

A. Spacecraft Description and Modification Summary

The HEAO is a standardized spacecraft across the three Block I missions with minor changes made to accommodate mission peculiarities. The spacecraft is shown in Figure 7. All subsystems are HEAO-B subsystems except the communications and data management subsystem, which is an HEAO-C design that is compatible with TDRSS. The total spacecraft weight is 1400 lb. Many of the HEAO components or their derivatives, such as reference gyros, star trackers, reaction wheels, 20 A-h batteries, and transponders are the same components that are being selected as NASA standard components.

The HEAO spacecraft provides modular accommodation for equipment at the bay level and equipment modularity at the component and lower levels. The length of the spacecraft is only 33 in., which allows good packaging efficiency of payloads in the orbiter bay and thus enhances the cost-saving possibilities of flight-sharing with other payloads. The spacecraft diameter is less than 92 in. across corners, thus allowing compatibility with many expendable launch vehicles. The qualification test levels of the spacecraft structure exceed the presently defined environmental levels of the Shuttle and applicable expendable launch vehicles.

The modifications and associated delta weights for the HEAO spacecraft for the four Block II missions are shown in Table 3. The total number of changes required for any mission is small, and therefore costs are likewise expected to be small.

B. Structures

The spacecraft was evaluated utilizing a finite element model for structural compatibility with Block II payloads. The spacecraft interface with the Block II mission equipment occurs at either four or eight of the attachments provided for the Block I payloads. The spacecraft was suspected to be quite adequate structurally for Block II application, and rather than evaluate the entire Shuttle flight loading spectrum, it was decided to consider initially the crash conditions. If positive load margins could be shown to exist for the crash conditions, then even higher margins would exist for Shuttle flight conditions.

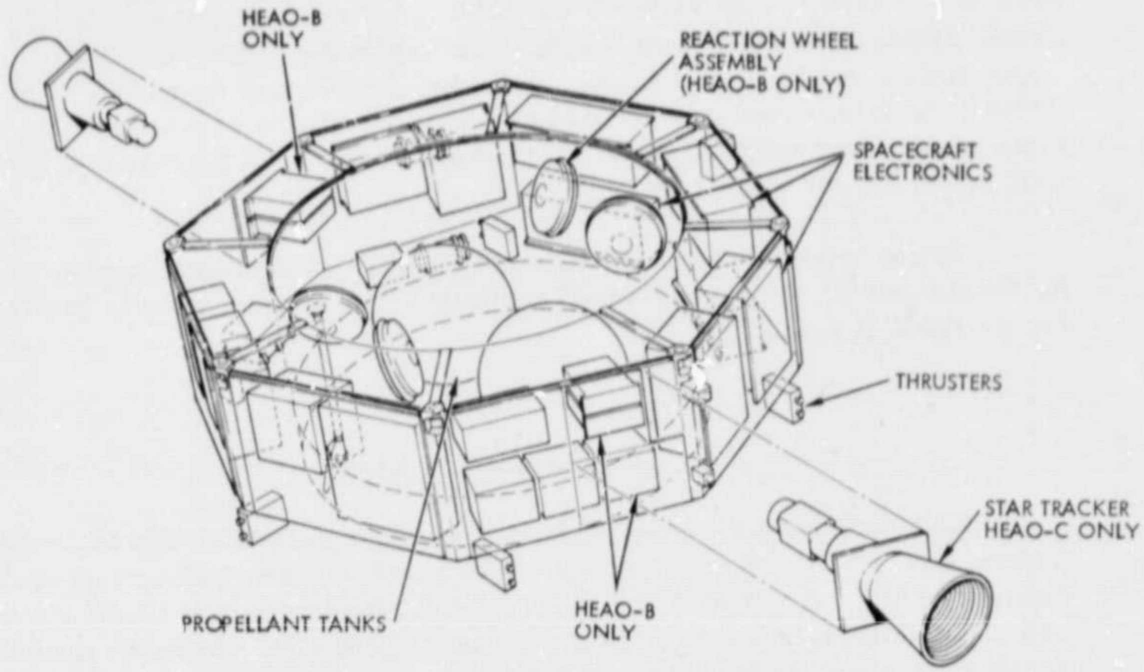

Figure 7. Basic HEAO spacecraft.

TABLE 3. HEAO SPACECRAFT

	Δ Weights (lb)			
	1.2 m Telescope	Cosmic	Gamma	LAMAR
Attitude Sensing and Control	+153	+184	+31	0
Delete Reaction Control System Tank (1) and Relocate Tank (1)	-17	-17	0	0
Replace Reaction Wheels (4) and Electronics	+170	+170	0	0
Add Star Trackers (2) and Electronics	0	+31	+31	0
Modify Control Logic	0	0	0	0
Electronics	0	0	0	0
Communications and Data Management	-12	-12	-12	-12
Replace Tape Recorders and Interfaces (2)	-12	-12	-12	-12
Modify Data Acquisition Rate	0	0	0	0
Structural/Thermal	+15	+15	+15	+15
Equipment Mounting Hardware	+15	+15	+15	+15
Total	+156	+187	+34	+3

Note: Quantities in parentheses denote number of items added or changed.

The ultimate reaction loads at the spacecraft/payload interface were on the order of 4600 lb longitudinally and 2500 lb laterally for the four-point mount (worst case). The spacecraft design loads are on the order of 18 000 lb longitudinally and 5000 lb laterally, so a considerable margin exists. The deflections in the spacecraft were likewise determined to be low (0.02 in. for eight attachments and 0.03 in. for four attachments), and the stresses were well within the allowable range.

It was concluded from this analysis that the structural capability of the HEAO spacecraft, even under crash conditions, far exceeds what is required for the Block II missions.

C. Thermal Control

The changes to the HEAO spacecraft were assessed briefly to determine if there was any impact on the design of the spacecraft thermal control system. The only significant change in power to be dissipated within the HEAO spacecraft was in the Attitude Sensing and Control System (AS& CS), where the power increased approximately 31 W. Of this, 16 W were from reaction wheels (which are mounted in the central cylinder) and 15 W were from associated electronics (which are located in two equipment bays). The surface area in these mounting locations is more than adequate to accommodate these additional power levels. Although battery loads are slightly higher than those of the Block I missions, analysis has indicated that battery compartment temperatures should remain within acceptable limits.

The shunt radiator should not require resizing, since its load should be approximately the same for the Block II missions as for the Block I missions. Any unforeseen excess loads could be eliminated by rolling the spacecraft so that the solar array is slightly off-Sun. Also, analysis indicates that the radiator could be operated at a slightly higher temperature, if necessary.

D. Attitude Sensing and Control

The 1.2 m X-Ray Telescope or instrument line of sight (LOS) must point within 30 arc s of the target. Once data taking begins, the LOS must stay within a 30 arc s stability error envelope over a 1 hour period. The LOS can deviate within the stability envelope as long as its rate of change (stability rate or jitter) does not exceed 0.5 arc s/s. The allowable stability envelope must

always be within the specified pointing error envelope. Target reacquisition accuracy after occultation is only required to the pointing accuracy levels for all Block II missions. Thus, data taking can be periodically interrupted for momentum management, and long pointing durations will not impose any problems on the AS& CS.

The LAMAR requirements are 6 arc min pointing accuracy, approximately 1 arc min stability, and 5 arc s/s stability rate. The stability rate requirements of both the X-ray telescope and the LAMAR will necessitate equipment such as star trackers and reaction wheels. However, both the gamma ray (0.5° pointing) and the cosmic ray (no pointing) requirements could be satisfied with a total Reaction Control System (RCS) approach similar to that used on HEAO-A.

As a goal, the slew rate was 10°/min for the 1.2 m telescope and LAMAR, which could have been a major actuator sizing criterion. However, the approach taken was to design the spacecraft to satisfy the other control requirements and to accept whatever slew capability resulted.

The environmental disturbances, and thus the control authority needed, depend upon the configuration parameters, such as principal inertia values. Assuming a 250 n. mi. orbit, a minimum reaction wheel sizing criterion per axis is the peak cyclic gravity momentum plus 50 percent for margin. This sizing criterion produces a Reaction Wheel Assembly (RWA) momentum requirement of 310 ft-lb-s for the 1.2 m X-Ray Telescope and 117 ft-lb-s for the cosmic ray observatory, which can be obtained by replacing the HEAO RWA with the Sperry Model 400 RWA. The current HEAO-B RWA's are adequate for the gamma ray, marginal for the LAMAR, and inadequate for both the cosmic ray and 1.2 m X-Ray Telescope. The HEAO-B RWA's were selected for the gamma ray and LAMAR missions, and the Model 400 wheels were used for the other two missions. The Model 400 produces 400 ft-lb-s momentum, is about 26 in. in diameter by 9 in. thick, and four units will fit within the HEAO spacecraft by deleting the current RWA's and one propellant tank. The other propellant tank would be relocated to the center of the spacecraft for the two missions and has enough propellant capacity so that the RCS can be retained and used for placement, backup, and retrieval modes.

Over a 2 year period the propellant requirements (about 850 lb for the 1.2 m X-Ray Telescope) would become prohibitive for momentum management (RWA wheel speed control) for all the missions except gamma ray. A Magnetic Torquer System (MTS) was selected for momentum management. The MTS consists of a three-axis magnetometer, drive electronics, and three orthogonal

electromagnets. The MTS dipole requirements range from 300 A-m^2 for the gamma ray to 6000 A-m^2 for the 1.2 m telescope on a per-axis basis.

A block diagram of the AS& CS is illustrated in Figure 8 along with the additions and changes needed to accommodate the HEAO Block II missions. Most of the HEAO components such as Sun sensors, reference gyros, star trackers, transfer assemblies, digital computers, and RCS can be used as is for Block II. Because the 1.2 m telescope and LAMAR have experiment-provided aspect sensors like the HEAO spacecraft, the spacecraft star trackers are not required for these missions, but the RWA and drive electronics must be replaced with larger units.

E. Reaction Control

Propellant weights for backup modes range from 17 lb on the gamma ray to 144 lb on the 1.2 m telescope. One tank can hold a maximum of 134 lb of hydrazine. Figure 9 presents a functional schematic of the HEAO-B spacecraft RCS. The shaded areas represent those components that are to be deleted for the X-ray telescope and cosmic ray missions. The two-tank RCS can be used for the other two missions to minimize changes from the Block I system.

As an option, a control system consisting of RWA's and an RCS (no magnetics) for momentum management and backup was sized for the X-ray telescope, cosmic ray, and LAMAR missions, and an RCS-only control system was considered for the gamma ray mission. Propellant loadings for these optional cases ranged from 362 to 988 lb, which would require additional tanks.

Mission control simulations were conducted to determine the HEAO Block II thruster actuation requirements. These requirements were then compared with the HEAO spacecraft thruster actuation capabilities to determine thruster lifetime compatibility for the HEAO Block II missions. The results of this simulation indicate that the HEAO spacecraft thruster is adequate to meet the number of actuations required of any one thruster on any HEAO Block II mission.

F. Communications and Data Management (C&DM)

All of the payloads were assumed to require TDRSS service because of the planned reduction in the Space Tracking and Data Network (STDN) ground stations after implementation of the TDRSS in 1979. Both the TDRSS S-band

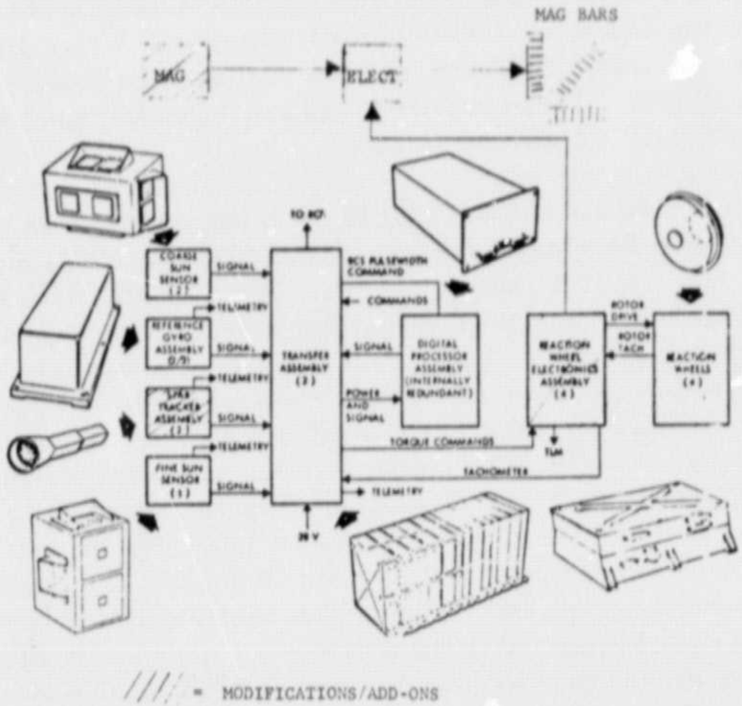

Figure 8. HEAO attitude control system modified for the Block II missions.

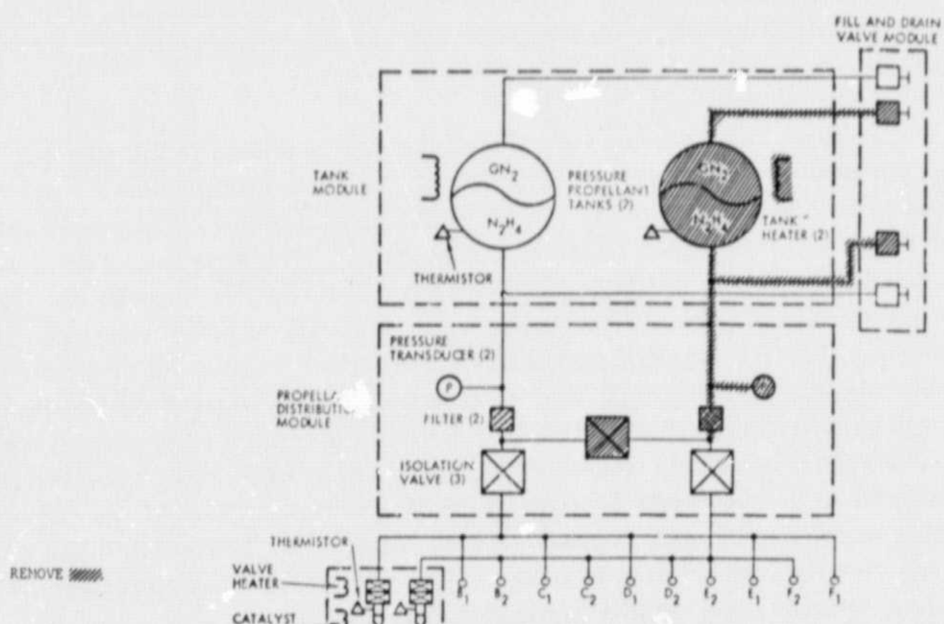

Figure 9. HEAO Block II RCS schematic for the magnetic torquer control option.

single access (SA) system and the TDRSS multiple access (MA) system appear adequate to accommodate the HEAO Block II missions. Table 4 gives the transmission rates, the command rates, and the total storage requirements for the four payloads studied. These requirements are dependent upon whether the TDRSS SA service or MA service is used.

Study and analysis of the HEAO Block II communications and tape recorder subsystem revealed four major issues. These issues center around the question of whether TDRSS MA or SA service is best for the HEAO Block II payloads, the advantages of having two antennas versus one antenna, the impact of not providing tape recorders, and the availability of the TDRSS. The availability of the TDRSS was a central issue upon which the other three major issues were dependent. Analysis of an available mission model indicated that the TDRSS SA service should be available to an HEAO Block II payload approximately 20 percent of the time and that MA service should be available approximately 80 to 90 percent of the time. As a result of the TDRSS availability analysis, the option of not having onboard recorders was not considered viable for a payload compatible with only the TDRSS SA option. Tape recorders are also preferred for the MA option to prevent loss of over 10 percent of the science and engineering data. A two-antenna configuration is preferred because of the additional redundancy and the improved coverage provided by the second antenna. The trade between TDRSS SA and MA compatibility did not reveal any major advantage in choosing one TDRSS service over the other. Both services are adequate for HEAO Block II missions. Although the SA system was selected in this study, it is anticipated that the HEAO Block II missions will use the same service used by the HEAO-C mission.

A block diagram of the C& DM system is shown in Figure 10. The block diagram indicates the modifications to the TDRSS-compatible HEAO-C system required to accommodate the HEAO Block II missions. The communications and tape recorder subsystem utilizes two standard TDRSS transponders and is capable of transmitting up to 32 kbps of real time and up to 128 kbps of recorded data simultaneously via the TDRSS utilizing 3 W of RF output power and 2 ft dish antennas. The SA option is capable of receiving commands at a rate of 300 bps via the TDRSS utilizing a pair of omni antennas. The present HEAO tape recorders are replaced with two NASA small standard tape recorders for the HEAO Block II missions because the record rate of 6.4 kbps for the present recorders is not adequate for the Block II missions. These recorders are capable of recording and reproducing at rates up to 1 Mbps and are capable of storing up to 4.5×10^8 bits of data. The subsystem uses approximately 30 W for the SA option and weighs approximately 120 lb.

TABLE 4. HEAO BLOCK II PAYLOAD REQUIREMENTS

Parameter	1.2 m X-Ray Telescope	Cosmic Ray	LAMAR	Gamma Ray
Data Acquisition and Record Rate	7.2 kbps	16.5 kbps	32 kbps	26.6 kbps
TDRSS SA Option[a]				
Transmission Rate (RT/Dump)	7.2 kbps/ 28.8 kbps	16.5 kbps/ 66 kbps	32 kbps/ 128 kbps	26.6 kbps/ 106.4 kbps
Command Rate	300 bps est.	300 bps est.	300 bps est.	300 bps est.
Total Data Storage (bits)	4.3×10^7	9.9×10^7	1.9×10^8 [b]	1.6×10^8
TDRSS MA Option[b]				
Transmission Rate (RT/Dump)	7.2 kbps/ 7.2 kbps	16.5 kbps/ 16.5 kbps	32 kbps/ 16 kbps	26.6 kbps/ 13.3 kbps
Command Rate	300 bps est.	300 bps est.	300 bps est.	300 bps est.
Total Data Storage (bits)	8.6×10^6	2×10^7	3.8×10^7	3.2×10^7

a. TDRSS assumed available 20 percent of the time.

b. TDRSS assumed available 80 percent of the time.

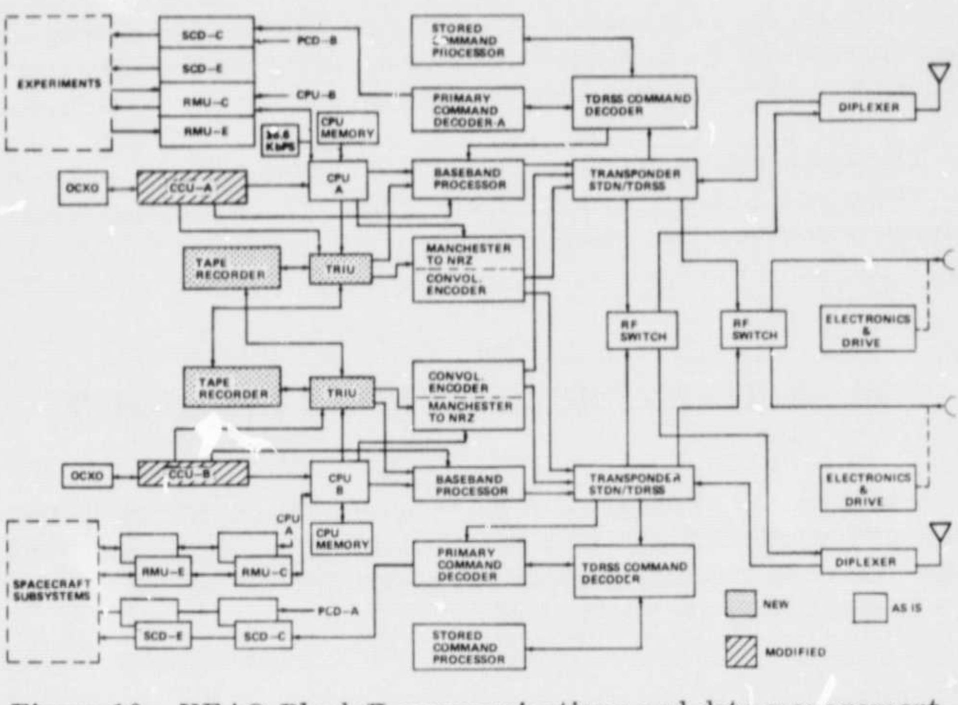

Figure 10. HEAO Block II communications and data management.

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The command and data handling subsystem has basically the same hardware as the present HEAO which utilizes a CDC-469 computer and a data bus system. The only required change is an increase in the data acquisition rate from 6.4 to 32 kbps. It appears that this can be accomplished with minor modifications. The total subsystem weighs approximately 65 lb and requires approximately 81 W of power.

G. Electrical

The primary requirement is to provide power for approximately 2 years. A secondary requirement is to select standard or readily available equipment for the economical construction of the Block II power system. These requirements can be met using the HEAO electrical system and fixed solar arrays.

Table 5 shows estimated power requirements for the four HEAO Block II missions. While the Block II power requirements are slightly greater than those for which the Block I spacecraft was designed, the HEAO Block I electrical system is readily usable for the Block II missions. Figure 11 presents the block diagram of the HEAO Block I electrical system as modified to meet these requirements. The HEAO Block II power requirements, as well as the desired longer life, require that the solar arrays be larger than those of the Block I system. The Block I arrays are constructed of several standard modules, and one of these, the Large Rectangular Module (LRM), was selected as a building block for the Block II array. The gamma ray observatory requires 12 LRM's and the other three missions 14 LRM's to satisfy the power requirements.

The spacecraft portion of the electrical system requires minor modifications. The mission peculiar items such as solar panels, wiring harness, and experiment accommodation assemblies are adaptations from the HEAO components.

VI. MULTI-MISSION SPACECRAFT APPLICATION

A preliminary assessment of the multi-mission spacecraft relative to the HEAO Block II missions was conducted using the limited MMS data from the "Low Cost Modular Spacecraft Description" document, X-700-75-140, May 1975, Goddard Space Flight Center.

TABLE 5. HEAO BLOCK II POWER REQUIREMENTS

	1.2 m X-Ray (W)	Cosmic Ray (W)	LAMAR (W)	Gamma Ray (W)
ACS				
Attitude Sensing	87	97	87	97
Attitude Control	136	126	95	90
C& DM	128	128	128	128
Experiment Complement	272	269[a] (185)	335	225
Total Power	623	620[a] (536)	645	540

a. Operational duty cycle of 71 percent applied where feasible; the superconducting magnetic spectrometer lifetime is only 1 year, giving the lower power requirement for the second year.

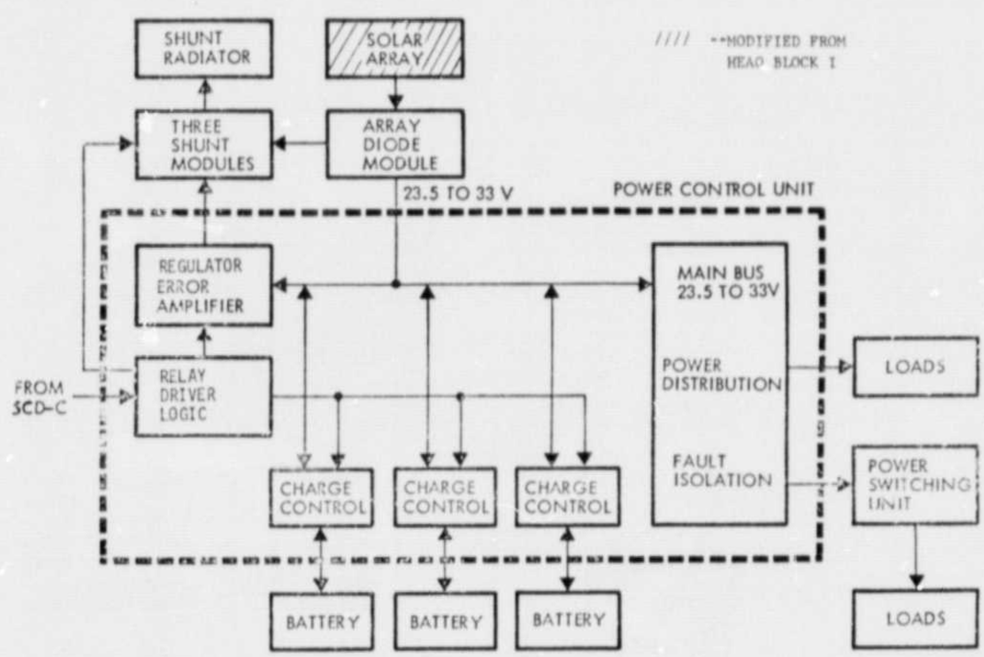


Figure 11. HEAO electrical system block diagram.

The approach was to utilize the "standard" MMS, as defined in report X-700-75-140, and to define the additions and changes required for the HEAO Block II missions. The MMS physical and functional parameters were assumed correct and compatible with each other, i.e., it was assumed that the MMS performance could be achieved within the weight and volume numbers stated. However, some reason for concern became apparent during the study as to whether these assumptions were valid because there is no analysis provided in the MMS document. The MMS numbers are considered soft because the MMS definition is 2 to 4 years behind the HEAO and its capabilities will probably change as the design is finalized. Thus, it is difficult and perhaps misleading to attempt to directly compare the HEAO with the MMS at present. MMS modifications have been identified, but have not been assessed in detail.

A. Spacecraft Description

There are four types of modules provided for the MMS: propulsion, ACS, C&DM, and electrical power modules. The MMS modules relative to their placement on the "standard" module support structure are illustrated in Figure 12, as are two propulsion modules. The smaller propulsion module is

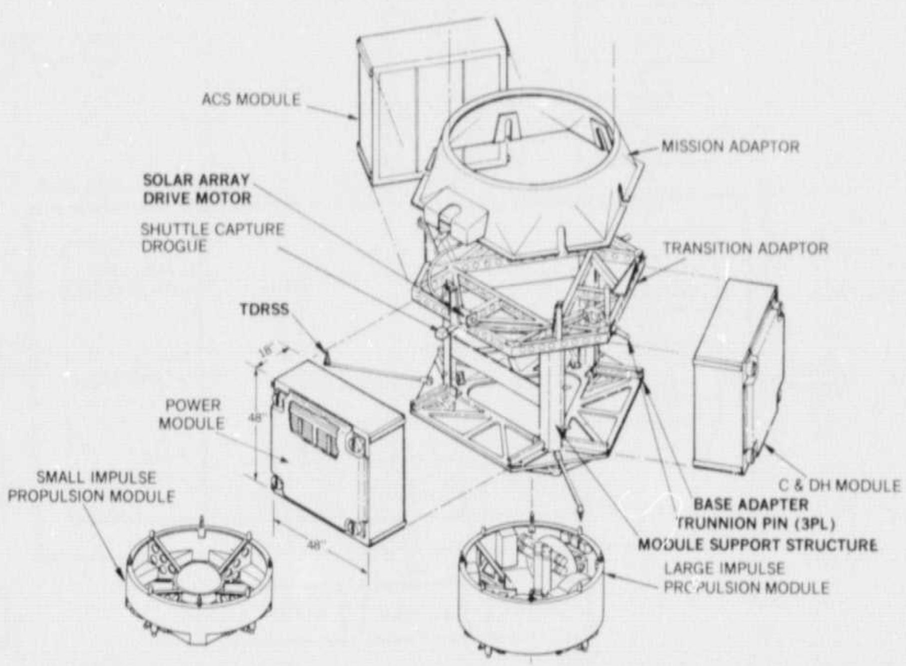


Figure 12. MMS module placement on support structure.

16 in. long and contains RCS and orbital adjust equipment with 55 lb of hydrazine as propellant. The larger module is 27 in. long and provides the same RCS functions as the smaller module, but also contains larger reaction wheels, torquer bars, etc., to supplement the ACS module momentum capability. A third RCS module (not shown) is approximately 76 in. long, and has kick stage capability in addition to the functions of the smaller modules. It can contain up to 1050 lb of hydrazine. Literature from Goddard Space Flight Center indicates that the components for the MMS spacecraft propulsion module exist. However, some components, such as the tank for the large module, require requalification with an expulsion bladder. The RCS thrusters also require requalification to attain the specified thrust level.

The ACS module contains sensors, electronics, and actuators such as reaction wheels and magnetic torquer bars. The four 15 ft-lb-s RWA's are considered standard equipment. If larger RWA's are required, they are added in the propulsion module. All the components needed for attitude control functions except the coarse Sun sensors and digital processors are housed within the ACS module. The inclusion of the magnetic torquers in the same module as the reaction wheels, star trackers, rate gyros, and other sensitive equipment seems likely to pose interference problems. No analysis could be found to provide information on this problem.

The computer, transponders, command demodulators, and data handling equipment such as recorders and multiplexers are housed in the C&DH module. The transponders are S-band units designed to transmit to the STDN at up to 640 kbps. The basic MMS is not TDRSS compatible, but add-on equipment can provide this compatibility. The recorders are mission-peculiar equipment that must be added to the basic C&DH module.

The coarse Sun sensors are mounted on the solar panels, which are mission-peculiar add-on equipment. The power module contains charger/regulator units and up to three 20 or 50 A-h batteries. The types of batteries, however, cannot be mixed on a given mission. The electrical power module appears to have equipment density too great to allow adequate clearances for cables, connectors, mounting brackets, access for tools or hands, etc. Such packaging density allows insufficient room for growth and might also pose a thermal control problem.

B. Observatory Configuration and Module Modifications

Figure 13 shows the 1.2 m X-Ray Telescope observatory with the MMS mounted on the aft end. The ability of the standard MMS structure to be mounted in such a cantilevered fashion could not be verified from the data available on the MMS. The observatory is approximately 5 ft longer than the corresponding observatory with the HEAO spacecraft; hence, it requires more space in the orbiter bay. This packaging inefficiency would be translated into reduced flight-sharing capability, with resultant launch cost implications.

Another configuration was also investigated, wherein the ACS, C&DM, and power modules were mounted in a toroid fashion around the periphery of the telescope just forward of the carrousel and the propulsion module was mounted at the aft end of the telescope. This resulted in slightly reduced length and inertia values, but required a new module mounting structure in place of the standard MMS structure.

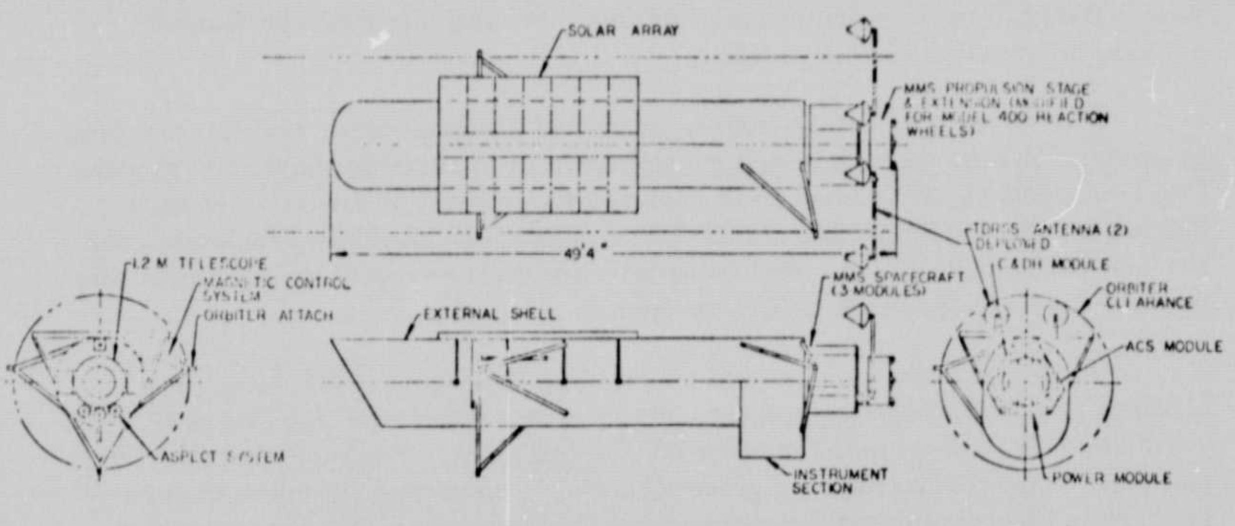


Figure 13. 1.2 m X-Ray Telescope with MMS.

The MMS actuators are considerably undersized and must be replaced with wheels on the order of the Sperry 400 ft-lb-s wheels.

The six 50 A-m^2 MMS magnetic torquer bars must be replaced with larger (6000 to 10 000 A-m^2 per axis) bars that are externally mounted. Figure 14 provides a block diagram of the components within the ACS module. This diagram has been marked to illustrate the deletions and additions required.

Figure 15 illustrates the required changes to the 27 in. module for application to the X-ray telescope mission. The module length must be extended an additional 10 in. to house the three Model 400 RWA's and their electronic drivers. The fourth RWA is housed in the ACS module and is skewed relative to those in the propulsion module. The six magnetic torquer bars in the propulsion module are deleted, and larger bars are mounted external to the solar panel or Shuttle interface structure.

The block diagram of the MMS C&DM module is provided in Figure 16 and shows the basic C&DM equipment and interfaces. Optional equipment is shown with broken lines. For the HEAO Block II missions, two NASA small standard tape recorders (10^8 bit recorders) are required. The HEAO Block II payloads will also require two high gain, S-band antenna systems compatible with the TDRSS.

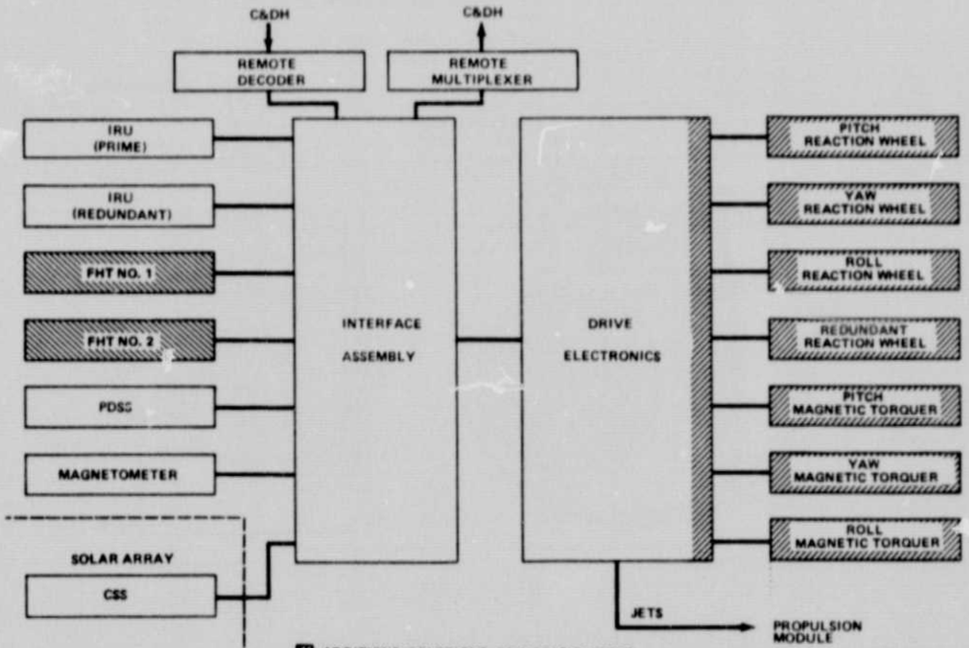
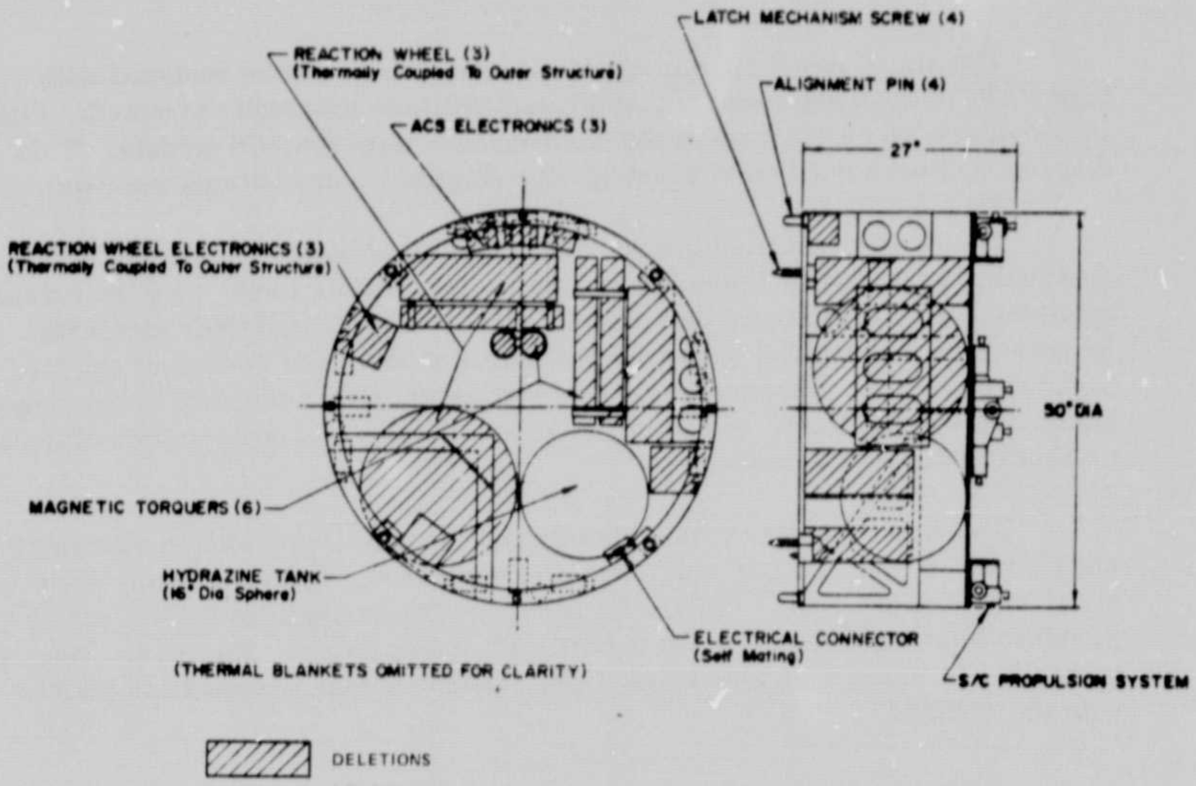
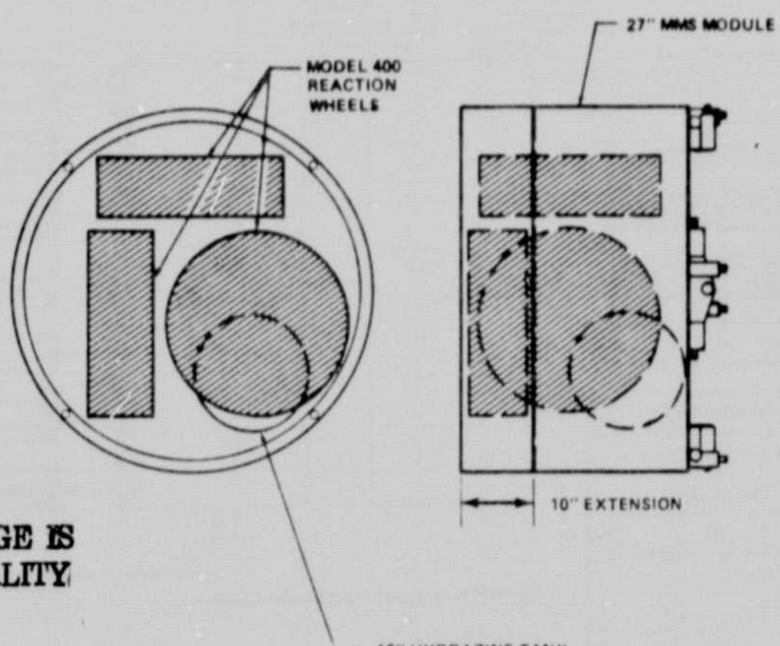


Figure 14. MMS attitude control system changes.



a. Required deletions.



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b. Required additions.

Figure 15. MMS propulsion module changes.

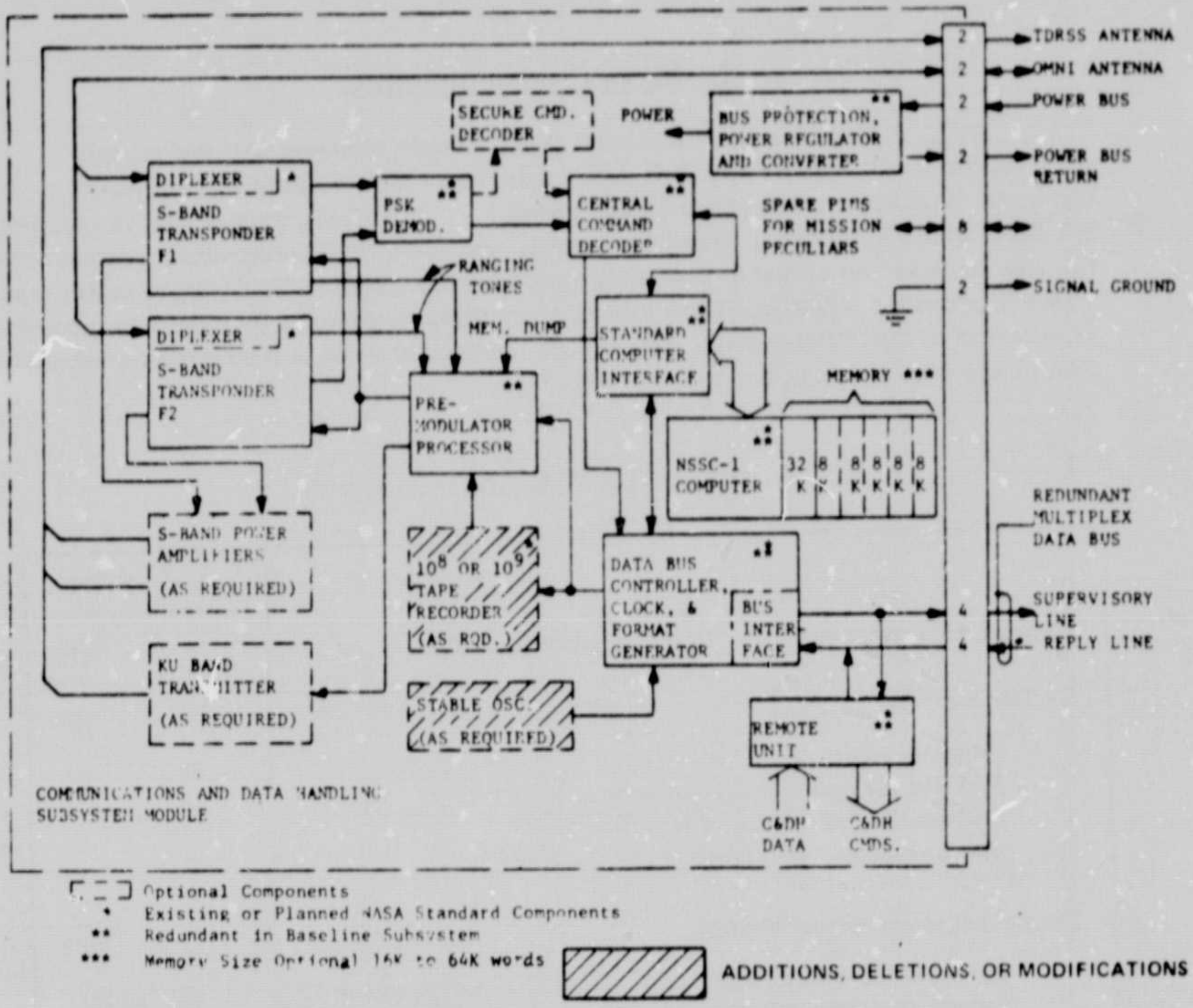

Figure 16. MMS C&DM module changes.

The basic MMS power module with three 20 A-h batteries was assumed to be utilized without modification; hence, no block diagram of it is shown. The MMS power subsystem is not optimized for Block II class missions and requires a larger solar array than the electrical system of the HEAO spacecraft.

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C. Mass Characteristics

Table 6 provides the estimated MMS module changes and the module weights for the 1.2 m X-Ray Telescope mission. The weights shown here for the basic modules are as given in document X-700-75-140, except that the weights for the module structure, thermal control, and electrical integration are prorated to each module and added to the equipment weights given in that weight statement. Table 7 provides a listing of the mission-peculiar equipment that must be added in addition to the MMS module changes previously defined and provides a tabulation of the total weights for the observatory.

TABLE 6. MMS MODULE WEIGHTS

	Weight (lb)	
Electrical Power Module (three 20-A-h batteries)		413
C& DH Module		293
Basic Module	226	
Add Standard Tape Recorders (2)	65	
Add Stable Oscillator (2)	2	
Add Software for TDRSS	0	
Propulsion/Actuation Module		308
Basic Module (one tank dry) SPS-1, Configuration II	203 (est)	
Delete Reaction Wheels and Electronics (3)	-102 (est)	
Delete Magnetic Torquers (3)	-21 (est)	
Add MA 400 Reaction Wheels and Electronics (3)	228	
AS& CS Module		371
Basic Module	427	
Delete Reaction Wheels and Electronics (4)	- 80	
Delete Magnetic Torquers (6)	- 30	
Delete Star Trackers (2)	- 22	
Add MA 400 Reaction Wheels and Electronics (1)	76	

TABLE 7. WEIGHTS FOR 1.2 m X-RAY TELESCOPE OBSERVATORY (WITH MMS)

	Weights (lb)	
Telescope		12 657
Instruments		2 464
MMS Modules		293
Electrical Power Module (1)	413	
C& DM Module (1)		
ACS Module (1)	371	
Propulsion/Actuation (RCS) Module (1)	308	
Mission-Peculiar Equipment		1 113
Propellant	55	
Magnetic Torquers (6)	424	
Cables (Inter-MMS Modules)	50	
Solar Array Frame and Struts	100	
Solar Arrays	144	
TDRSS Antennas and Gimbals	64	
Module Mounting Structure		
Cylindrical Extension for Reaction Wheels	15	
Reaction Wheel Mounting Modifications	10	
Mounting Structure Beams	100	
Cables (Extra-MMS)	78	
Standard MMS Structure	73	
Total Observatory		17 619
10 Percent Contingency		1 762
Total with Contingency		19 381

VII. CONCLUSIONS AND RECOMMENDATIONS

Although a detailed and exhaustive analysis has not been done for all four missions defined herein, all of the missions are feasible. The majority of the mission equipment for the Block II missions should be achievable within the present state of the art. Investigation is presently underway in some of the more critical areas, such as the large telescope mirrors, to determine the degree of effort required.

Some selected areas that require more specific penetration in future studies are the telescope mirror assembly design, the magnetic effects (if any) on the Invar 1.2 m X-Ray Telescope, and the magnetic effects in the cosmic ray payload. The LAMAR payload should be studied further in the area of structure design. Additional solar array options should be studied for the LAMAR and cosmic ray missions.

The missions should be achievable using the existing HEAO spacecraft design with the modifications defined herein, and the HEAO spacecraft should be easily adaptable to all four missions. No new technology effort is necessary on the spacecraft. The changes and additions required for the MMS tend to exceed those required for the HEAO spacecraft. The MMS system is 2 to 4 years less mature than the HEAO Block I spacecraft; hence, the analysis performed should be considered very preliminary. It is recommended that further studies of the Block II missions be undertaken utilizing the HEAO spacecraft as the baseline spacecraft, with further assessment of the MMS made as more data on it become available.

APPROVAL

HEAO BLOCK II STUDY EXECUTIVE SUMMARY

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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James A. Downey III
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